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FIP/1-3Ra

Long-pulse acceleration of 1MeV negative ion beams toward ITER and JT-60SA neutral beam injectors

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FIP/1-3Rb

Towards powerful negative ion beams at the test facility ELISE for the ITER and DEMO NBI system

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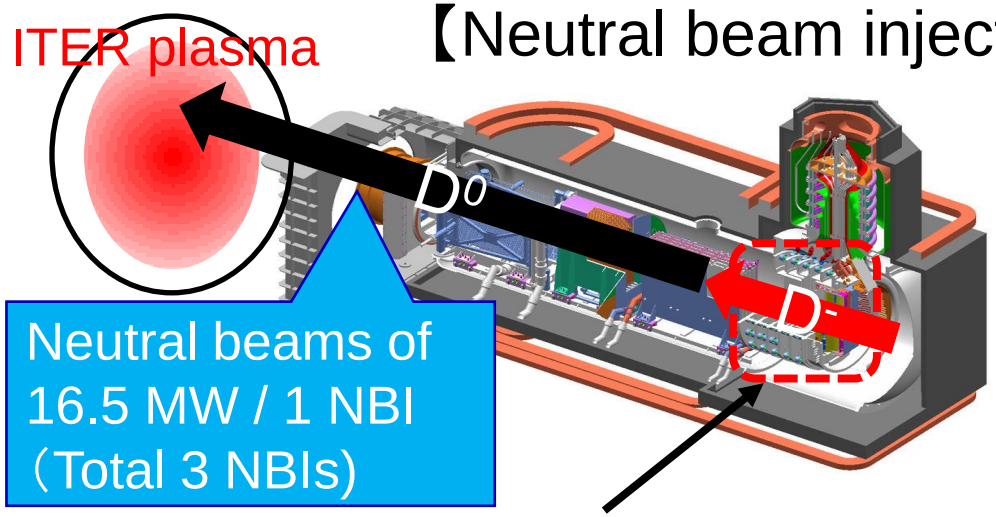
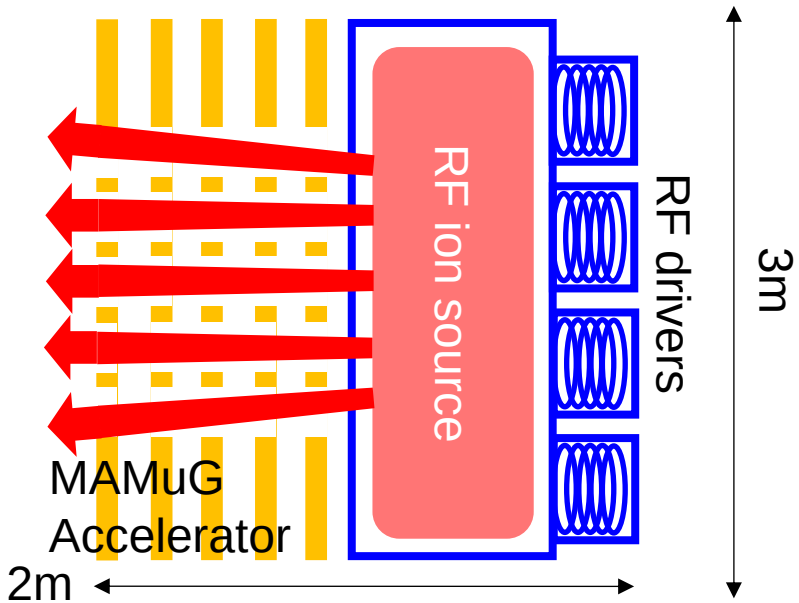
High power neutral beam injectors

【Neutral beam injector (NBI) for ITER】





Issues in RF ion source

- High current negative ion production/extraction using multi-RF drivers
- Stable negative ion production/extraction for long pulse

Issues in multi-aperture multi-Grid (MAMuG) accelerator

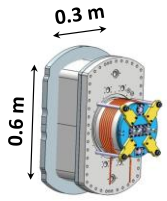
- Voltage holding with multi-grid
- Reduction of grid power load for long pulse

Activities toward the ITER NBI

RF ion source (IPP, Garching)

BATMAN

1-driver

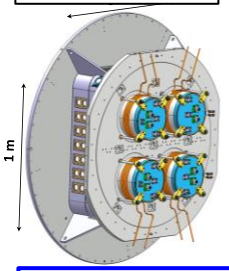


~1.5A, 6s

x4

ELISE

4-driver



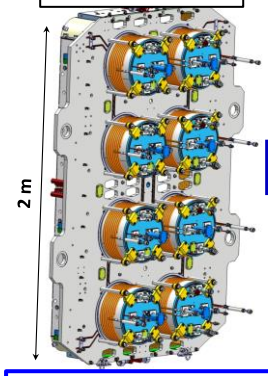
20 A, 3600s

x2

ITER NB test facility (RFX, Padova)

SPIDER

8-driver



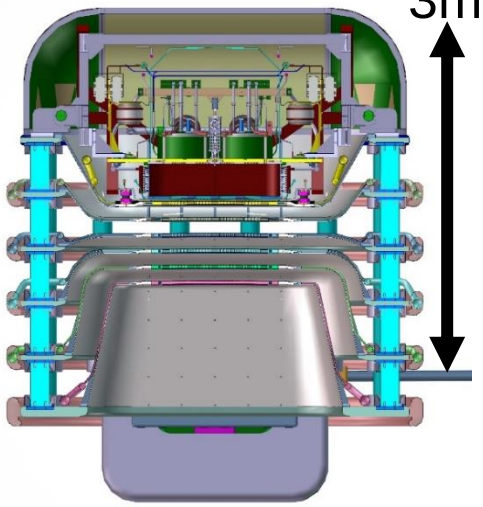
40 A, 3600s

ITER beam source (MITICA)

8-driver

Φ3m

3m

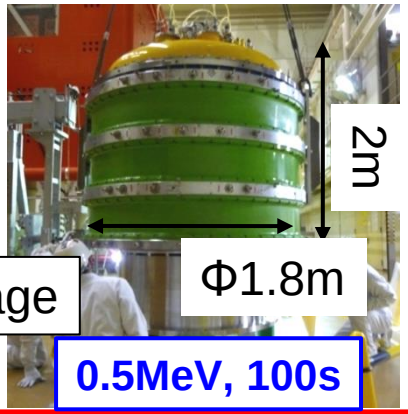


5-stage

1MeV, 40A, 3600s

MAMuG accelerator (QST, Naka)

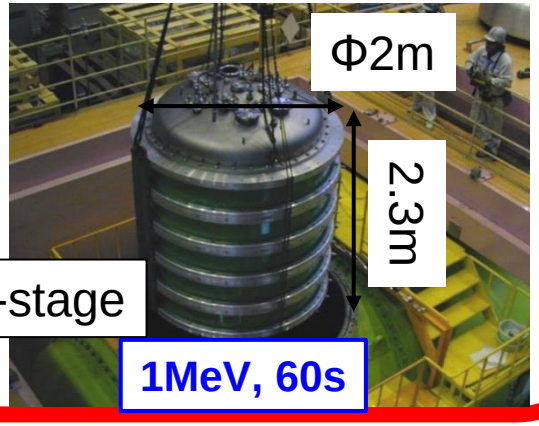
JT-60SA



3-stage

0.5MeV, 100s

1MeV test facility



5-stage

1MeV, 60s

EUROfusion IPP

Progress in IPP

Towards powerful negative ion beams at the test facility ELISE for the ITER and DEMO NBI system

ELISE test facility

Poster: FIP/1-3Rb (Tuesday)

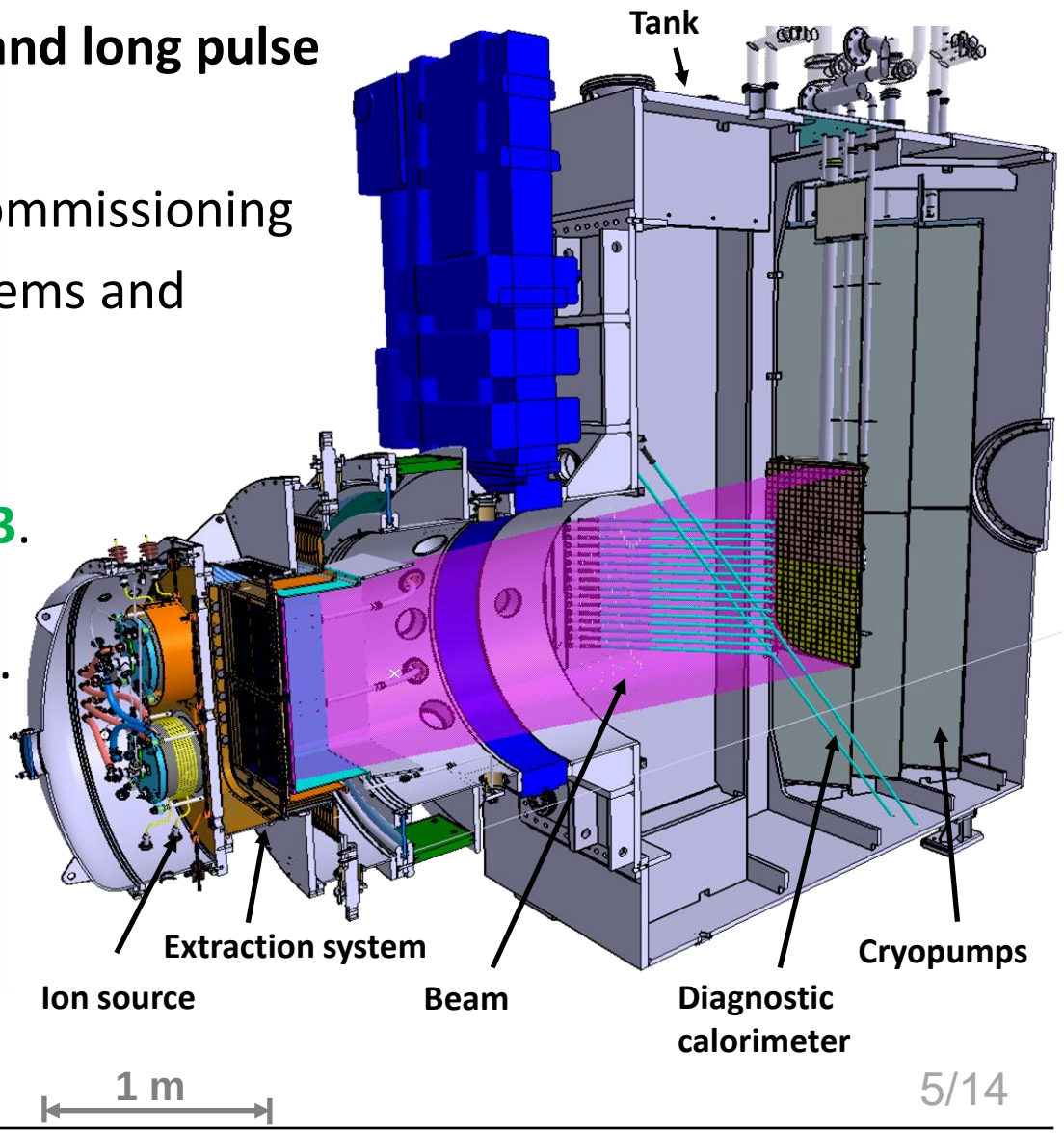
The ELISE test facility with a ½-size ITER RF ion source

4-driver in the ion source and ion extraction system.

- **To demonstrate high current and long pulse operation**
- **To provide input** for design, commissioning and operation of ITER NBI systems and European test facilities
  - Operation : Started since **February 2013**.
  - Long pulse test : Started since **October 2014**.

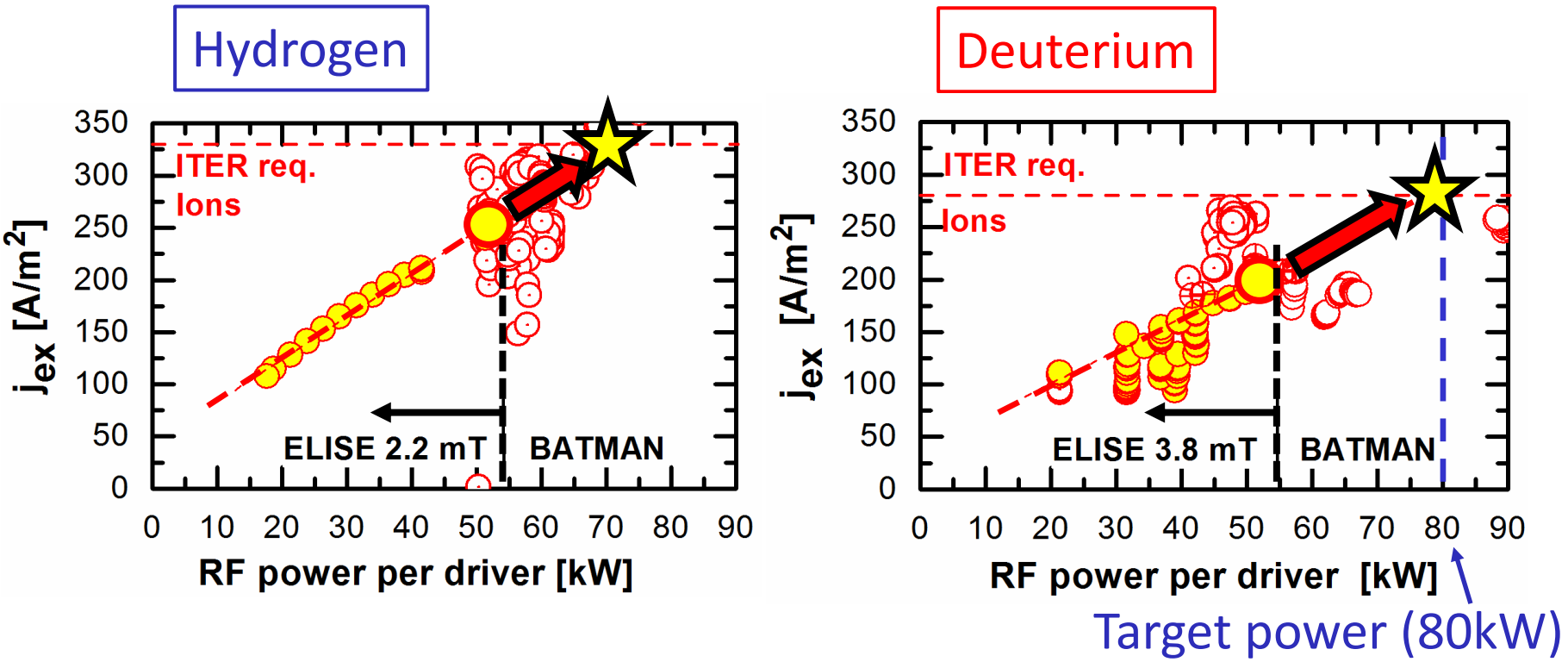
Keys for long pulse ion extraction:

- Beam homogeneity > 90 %
- Ratio of electron current for ion current < 1 at 0.3 Pa (ITER requirement)



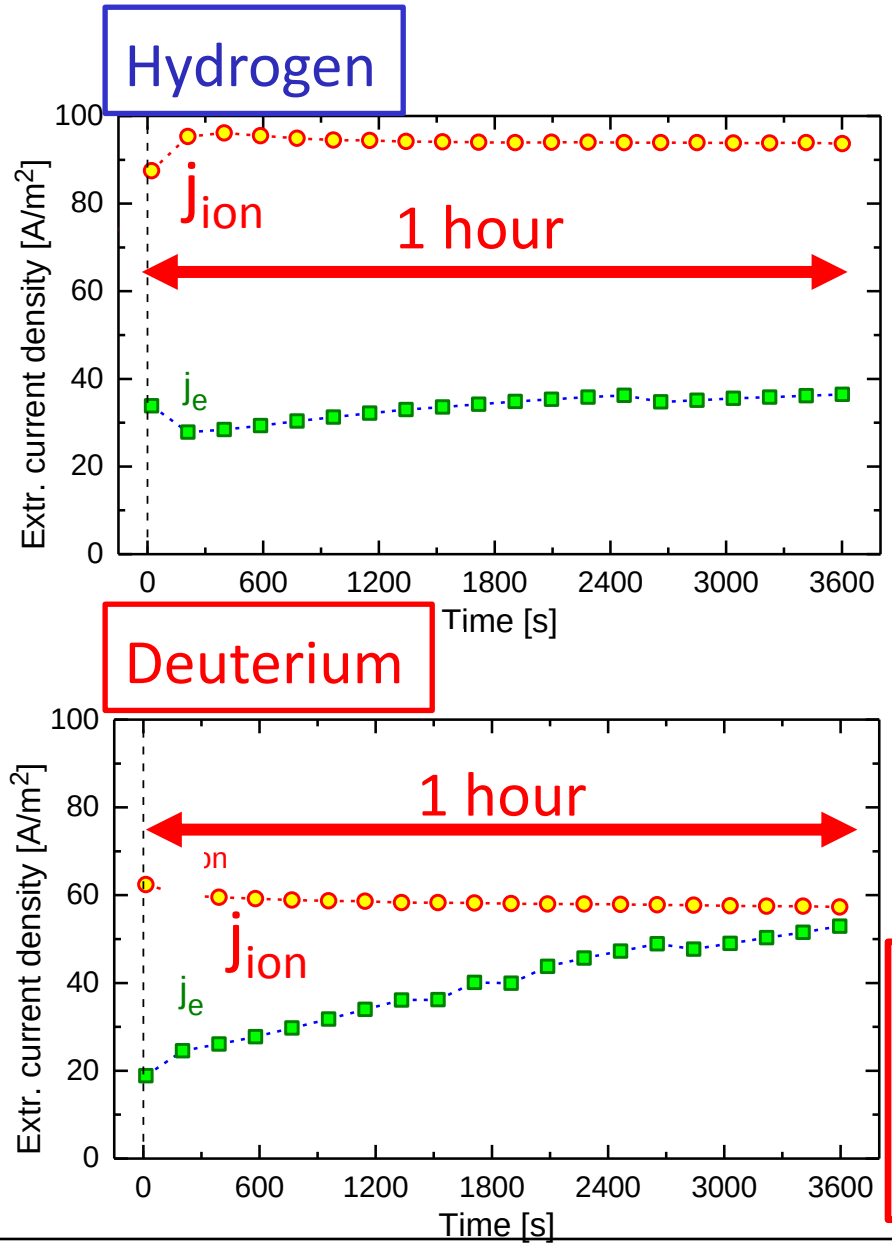
ELISE test facility – High current negative ion

20 s plasma, 10 s beam



- Extracted current density j_{ex} linearly increases with RF power.
- ITER requirement could be satisfied with 80 kW per driver by considering the results from BATMAN.
- Long pulse operation was tested with this range of RF power.

ELISE test facility – Long pulse operation



Hydrogen	Achieved	Target
$I_{ion,ex}$	9.3 A	33 A
RF power per driver	20 kW	80 kW
$I_{ion,ex}$/RF power	0.12 A/kW	0.10 A/kW

Deuterium	Achieved	Target
$I_{ion,ex}$	5.8 A	29 A
RF power per driver	20 kW	80 kW
$I_{ion,ex}$/RF power	0.073 A/kW	0.091 A/kW

- 1 hour operation was successfully achieved.
- Ion current / RF power is almost satisfied with the target value.

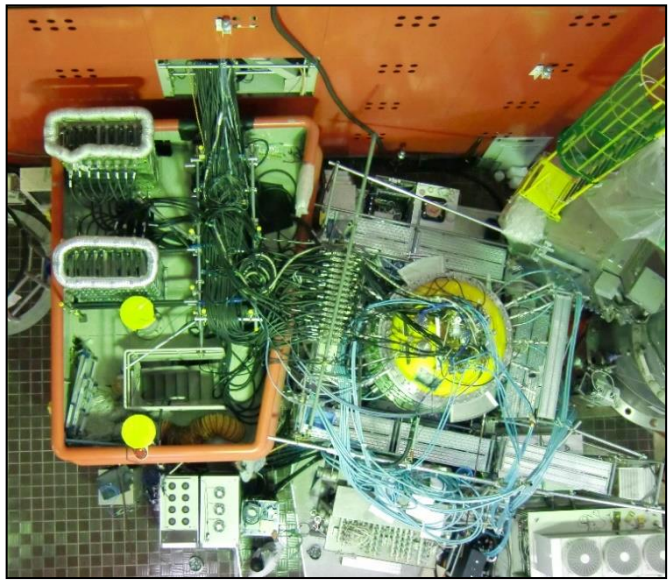
Summary: ELISE test facility

- Experiments on ELISE test facility has been started since Feb 2013 and had several long pulse campaigns since last FEC.
- Input RF power was still ¼ of the target value. However, the H- and D- ion currents linearly increase with RF power and could satisfy the ITER requirement with 80 kW of RF power.
- Long pulse operation of the H^- and D^- ion production/extraction was performed for the first time. 1 hour operation as the ITER requirement was successfully achieved.
- Next campaign with larger current production/extraction is being planned by tuning RF ion source.

Progress in QST

Long pulse beam acceleration toward ITER and JT-60SA NBI

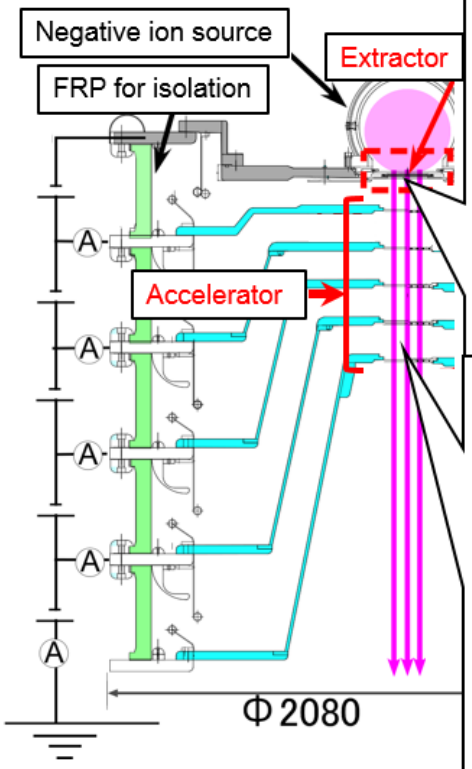
ITER prototype accelerator



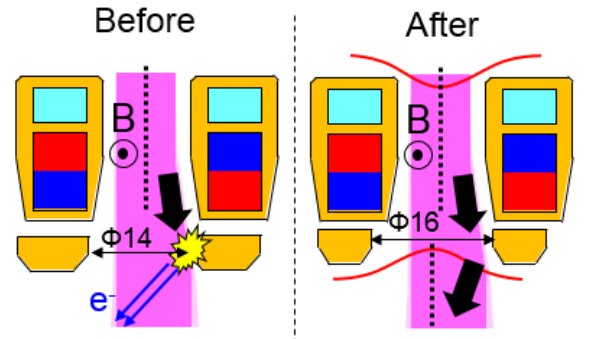
N-NBI system for JT-60SA

Toward the long pulse beam accelerations

Reduction of the grid power load has been performed as follows by FEC2014.

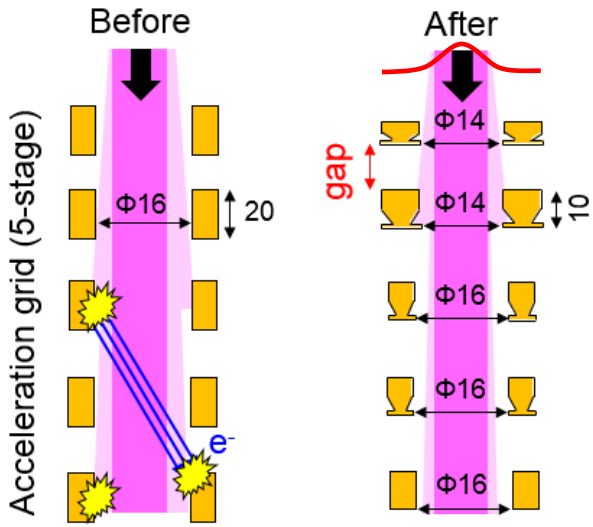


ITER prototype accelerator



Extractor

- Beam deflections due to magnetic field and space charge repulsion and direct interception of beam
- Corrected by the decentered and enlarged aperture in the extractor.



Accelerator

- Secondary electrons caused by direct interception of beam at the grid
- Intercept the diverged beam at the upstream grids in vertical angle. ⇒
- Decreases of aperture size
- Electron trap.

Remaining issue

- Grid power load on the final acceleration grid was still higher than the allowable level.

Achievement : 0.98 MeV, 0.4 s (FEC2012), 0.70 MeV, 60 s (FEC2014)

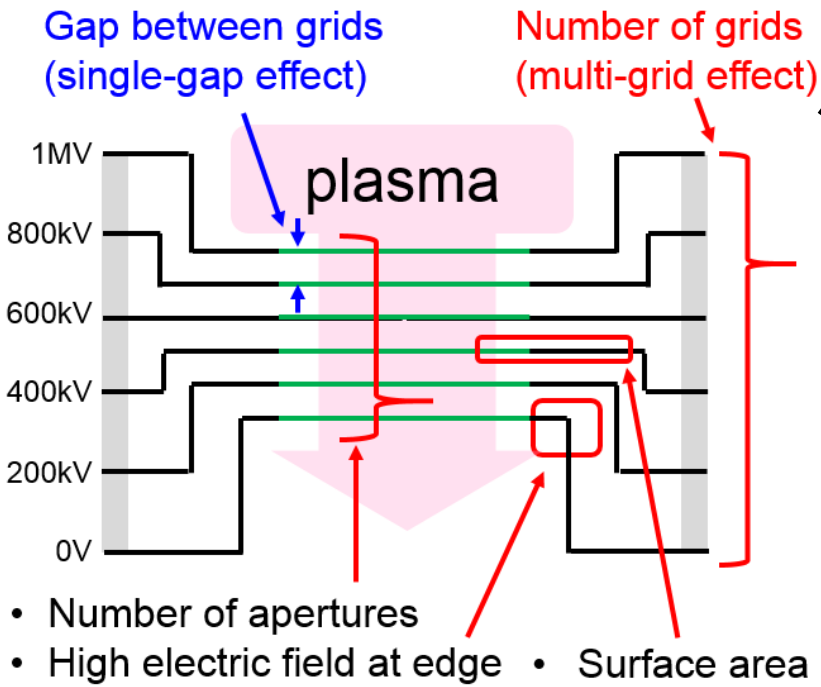
Remaining issue : 1 MeV, 60s beam acceleration.

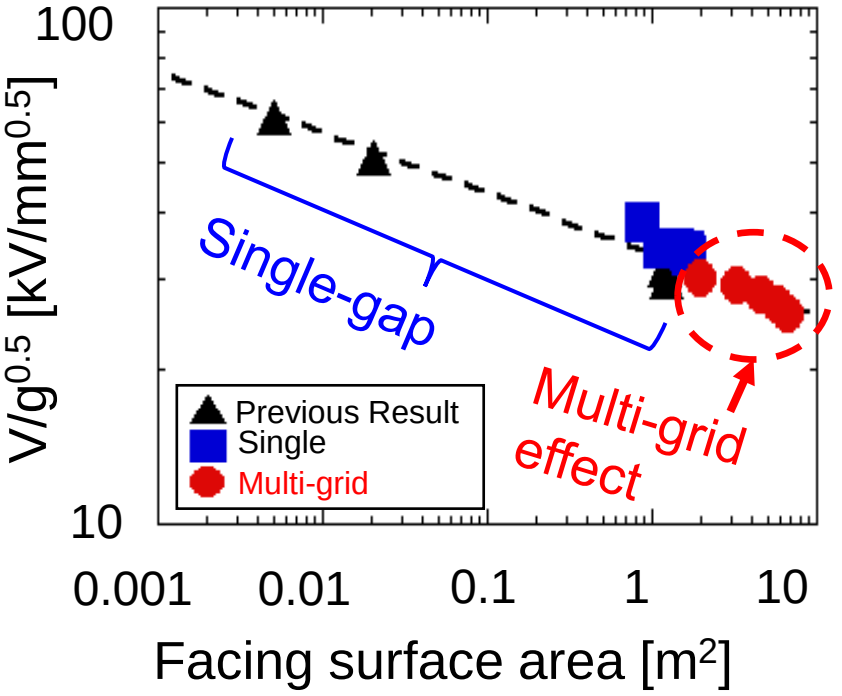
Optimization of beam optics is required by shorter acceleration gap. For this, voltage holding capability in MAMuG accelerator was investigated.

Multi-grid effect on voltage holding capability

By FEC2014, experimental data of voltage holding capability was obtained for each part.

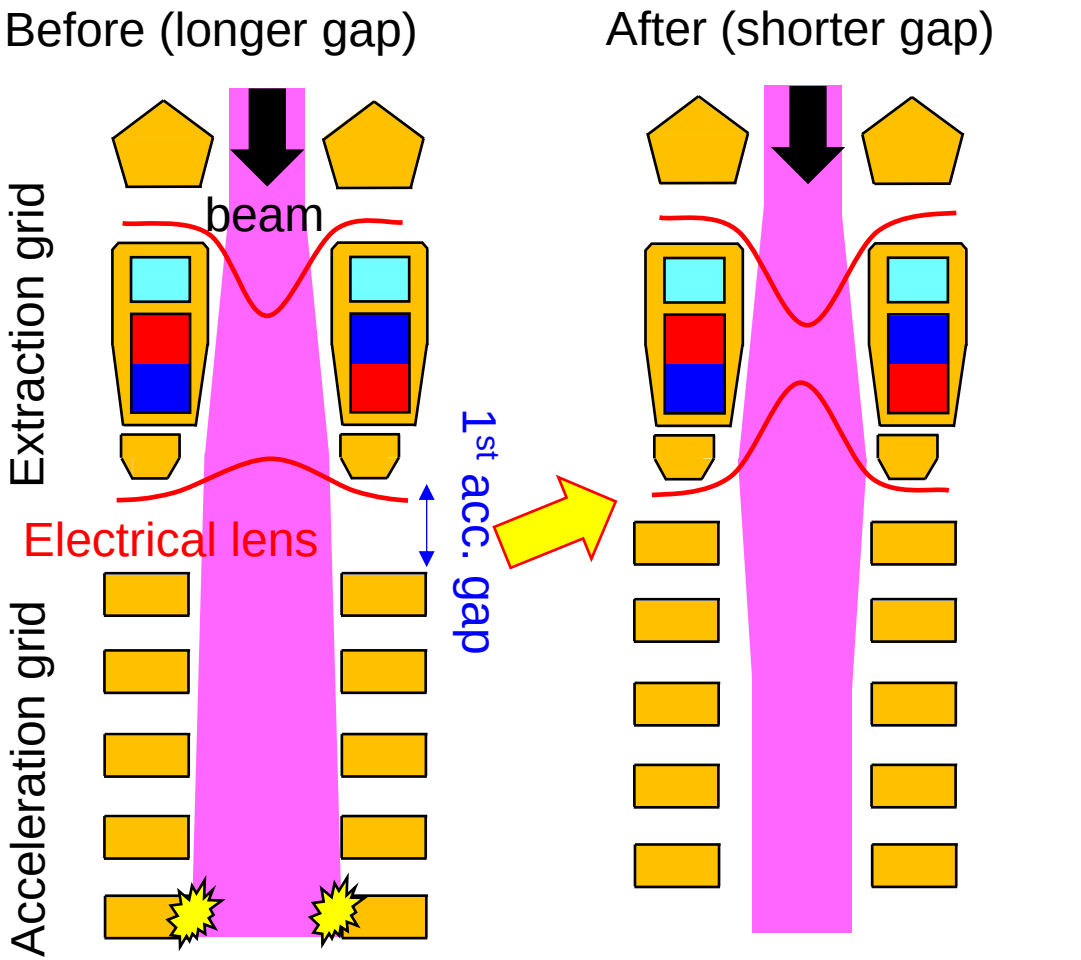
Newly obtained empirical scaling for multi-grid

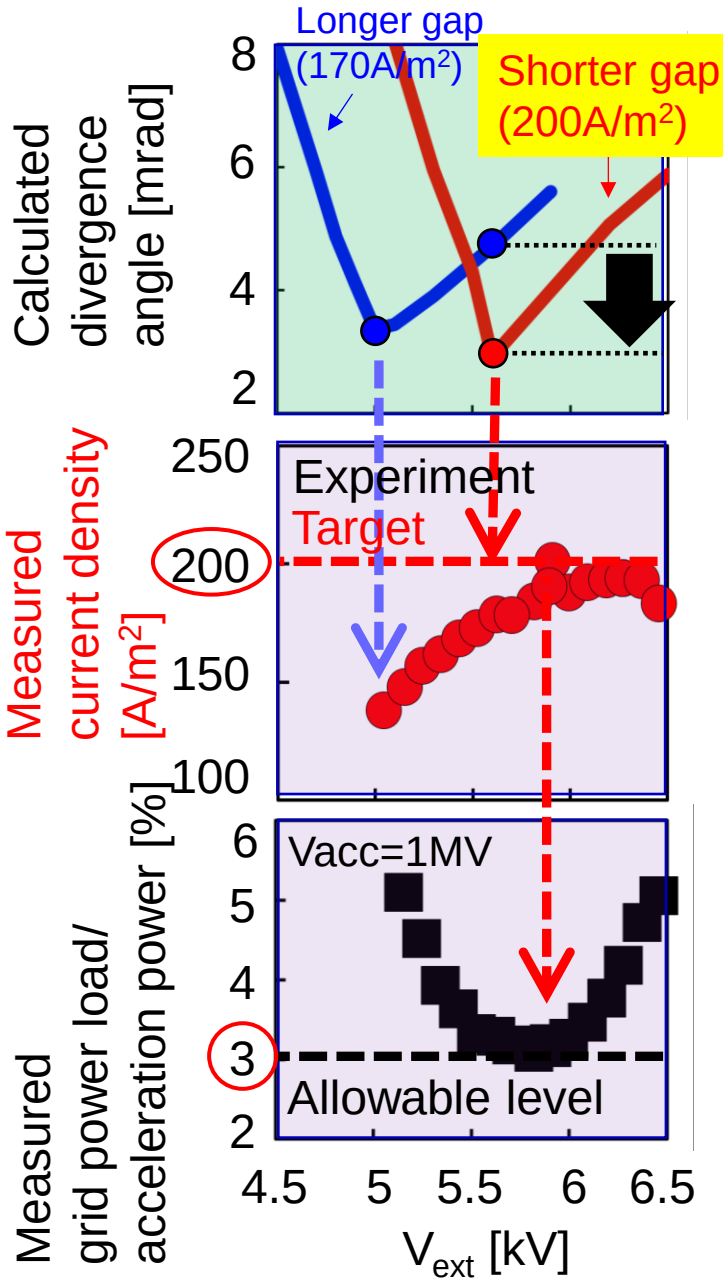




- This study clarified the voltage holding capability in multi-grid can be considered as that in the integrated surface area.
- By considering the empirical scaling, acceleration gap can be shortened to make electric field stronger and minimize the beam divergence.

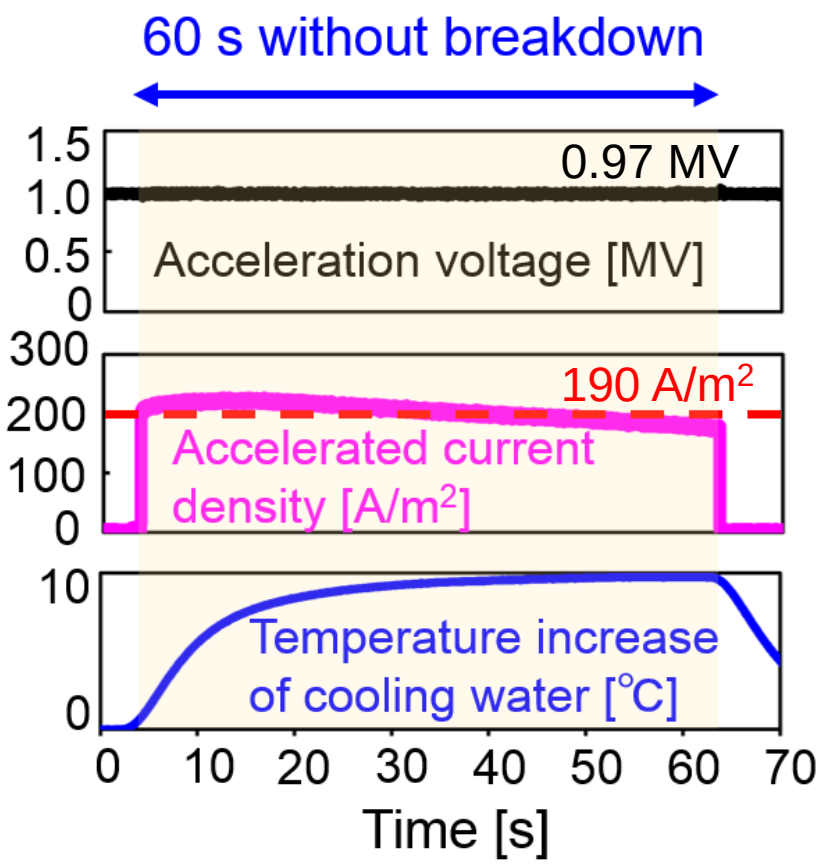
Tuning of acceleration gap length

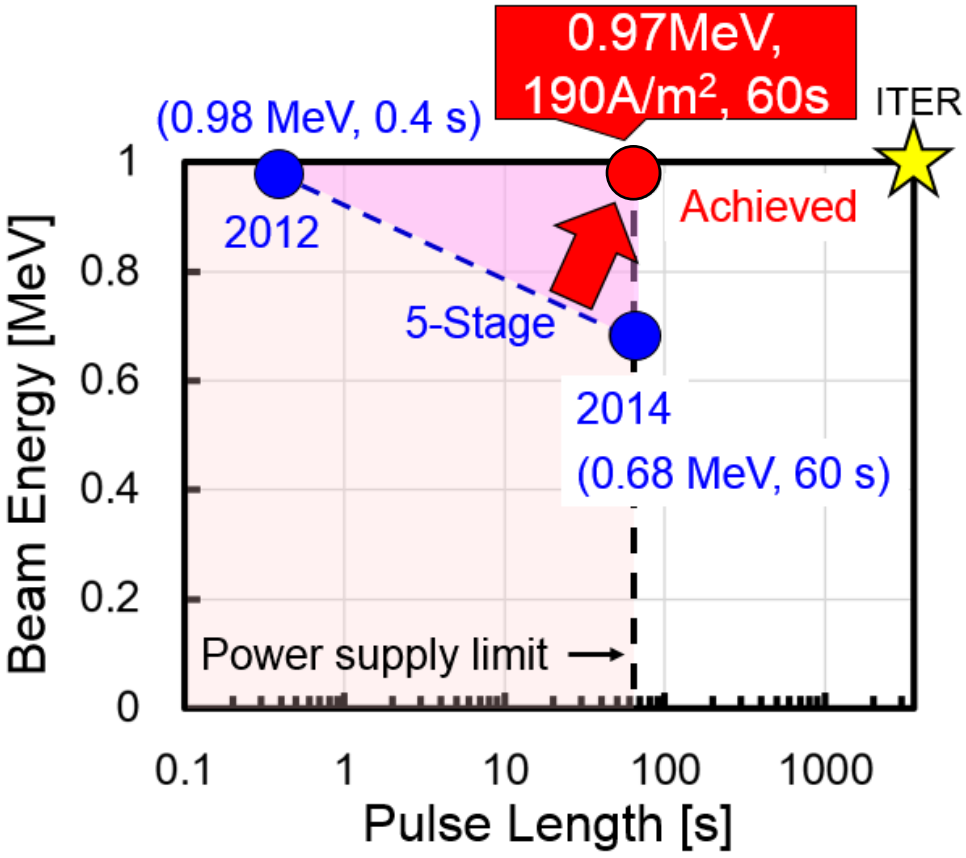




- Beam optics was successfully tuned for 200 A/m^2 by increasing electric field by 14%.
- Power load on each acceleration grid was reduced to the allowable level (3%).

Achievement of 1MeV and long pulse beam





- Demonstration of long pulse acceleration with ITER-relevant energy and current density of 0.97 MeV, 190 A/m^2 up to 60 s (power supply limitation) was successfully achieved.
- Cooling water temperature was saturated. There were no breakdown and no thermal damage during 60 s.

⇒ Further long pulse acceleration is available.

Summary

Long pulse acceleration of ITER-relevant beams of <u>0.97 MeV, 190 A/m^2, 60 s</u> was successfully demonstrated by the following R&D results in Japan.

- Multi-grid effect on voltage holding capability was experimentally investigated.
- Electric field in the first acceleration gap was tuned by satisfying the both requirements of voltage holding capability and beam optics.

Accelerator design of ITER and JT-60SA is being proceeded based on the R&D results.

Toward 1MeV, 40A, 1h beam : NB test facility (NBTF) in Italy

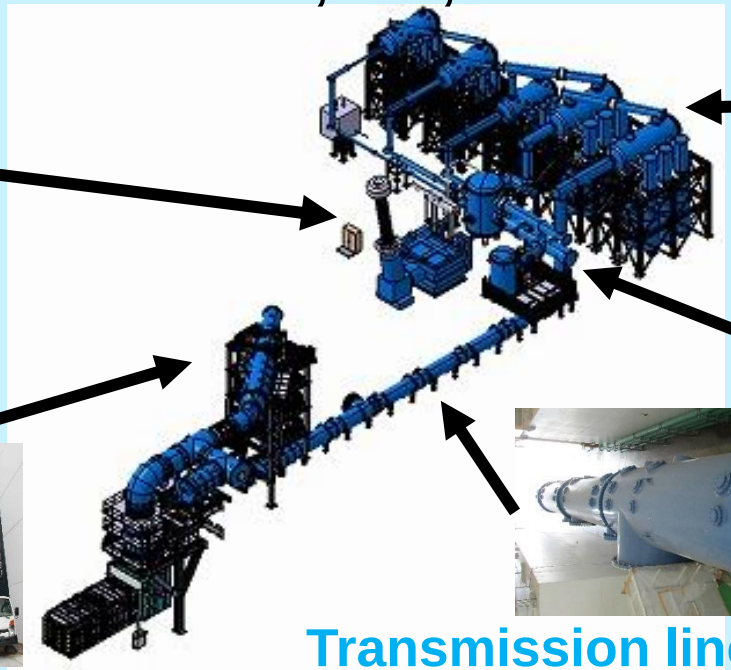
These achievements apply to the full size beam source in the NBTF for ITER.

In the NBTF site, construction of the 1MV system are in progress under good collaboration with IO/F4E/RFX/IPP colleagues..
Installation of 1MV power supply delivered from Japan has started from Dec/2015 as scheduled.

Transformers : 100 %, Transmission line 60 % completed.

1MV insulating transformer

HV power supply from Japan
1MV, 60A, 1h



1MV DC generator

Transmission lines